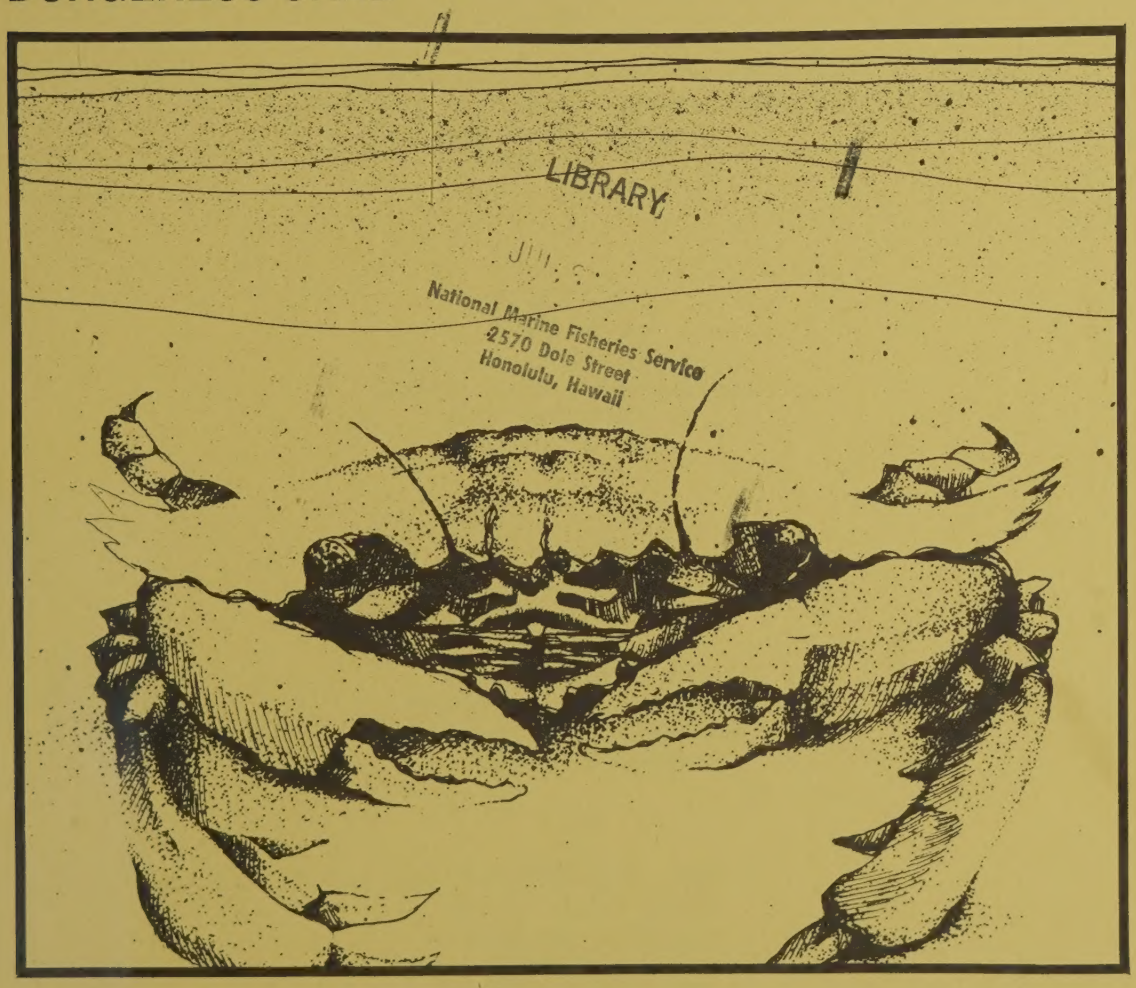
Biological Report 82(11.121)
December 1989

TR EL-82-4

Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest)

DUNGENESS CRAB



Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements
of Coastal Fishes and Invertebrates (Pacific Southwest)

DUNGENESS CRAB

by

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	*By*	*To Obtain*
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (° C)	1.8 (° C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces	28.35	grams
pounds (lb)	0.4536	kilograms
pounds	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (° F)	0.5556 (° F - 32)	Celsius degrees

CONTENTS

	Page
PREFACE	iii
CONVERSION TABLE	iv
FIGURES	vi
ACKNOWLEDGMENTS	vii
NOMENCLATURE/TAXONOMY/RANGE	1
MORPHOLOGY/IDENTIFICATION AIDS	1
REASON FOR INCLUSION IN SERIES	3
LIFE HISTORY	4
Mating	4
Eggs and Fecundity	4
Larvae	5
Juveniles	7
Adults	8
GROWTH CHARACTERISTICS	8
THE FISHERY	9
Commercial Fishery	9
Sport Fishery	12
ECOLOGICAL ROLE	12
ENVIRONMENTAL REQUIREMENTS	12
Temperature	12
Salinity	13
Temperature-Salinity Interactions	13
Substrate	14
REFERENCES	15

FIGURES

Number		*Page*
1	Dungeness crab	1
2	Distribution of the Dungeness crab in California	2
3	Abdominal differences between female and male Dungeness crabs	3
4	Life cycle stages of the Dungeness crab	6
5	Mean carapace width of male and female crabs from central California, 1977-1980	9
6	Dungeness crab landings by season for Pacific Coast states and the Province of British Columbia	10
7	Dungeness crab landings for central and northern California	11
8	Egg-brooding periods of the Dungeness crab at various laboratory seawater temperatures	13

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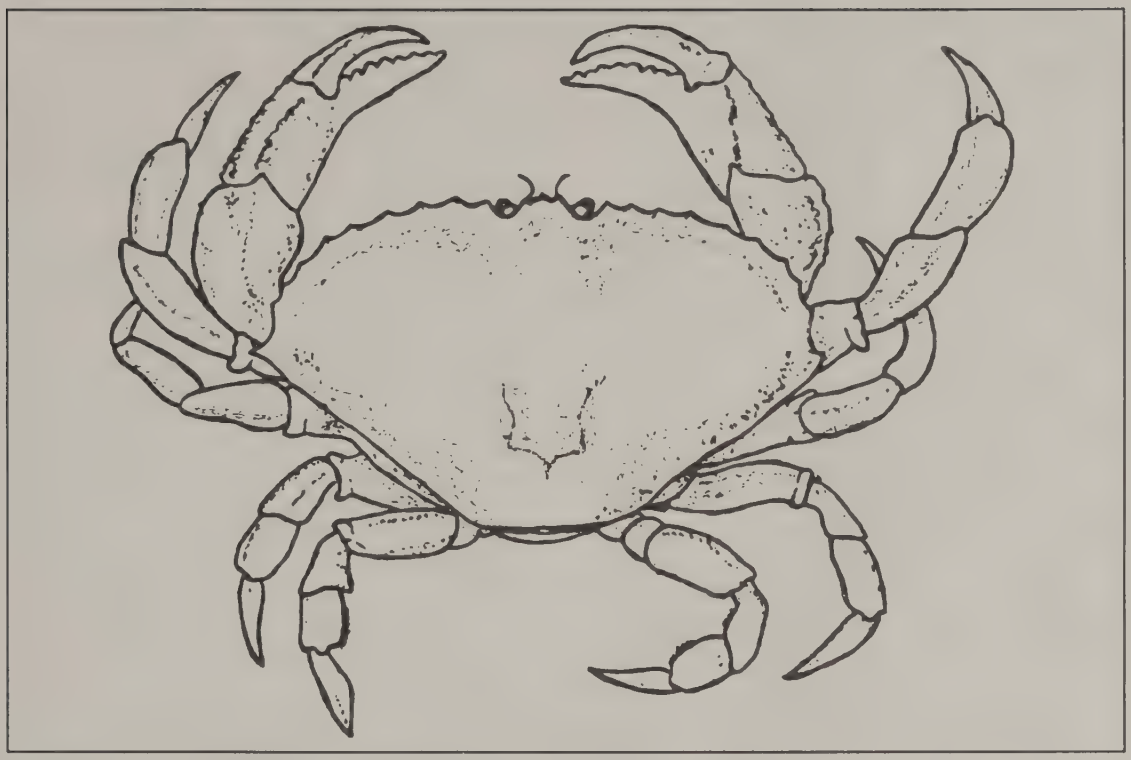

Figure 1. Dungeness crab.

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . . . *Cancer magister* Dana
Preferred common name . . . Dungeness crab (Figure 1)
Other common names . . . . . Pacific edible crab, edible crab, market crab, commercial crab

Class . . . . . Crustacea
Order . . . . . Decapoda
Infraorder . . . . . Brachyura
Family . . . . . Cancridae

Geographic range: Coastal waters along the west coast of North America from Unalaska Island in the north to Mexico in the south (Schmitt 1921; MacKay 1943; Butler 1961a; Mayer 1973). The species ranges from the intertidal zone to a depth of at least 180 m and inhabits substrates of mud, mud with eelgrass (*Zostera* sp.), and sand (Schmitt 1921; Butler 1956; Butler 1961; Stevens 1982). The distribution of the Dungeness crab in the Pacific Northwest and the ports of major commercial landings are shown in Figure 2.

MORPHOLOGY/IDENTIFICATION AIDS

Dorsal and ventral anatomy of *Cancer* crabs were illustrated by Warner (1977). The following morphology and identification aids were taken from Rudy and Rudy (1979). Size (type specimen): carapace 120.7 mm long x 177.8 mm wide. Color: beige to light brown with blue trim and hue, darkest anteriorly, often light orange below, sometimes light gray-purple below; inner sides of anterior feet and hands crimson, fingers not dark. Eyes: eyestalks short, orbits small. Antennae: antennules folded lengthwise: antennal flagella short, more or less hairy. Carapace: broadly oval, uneven but not

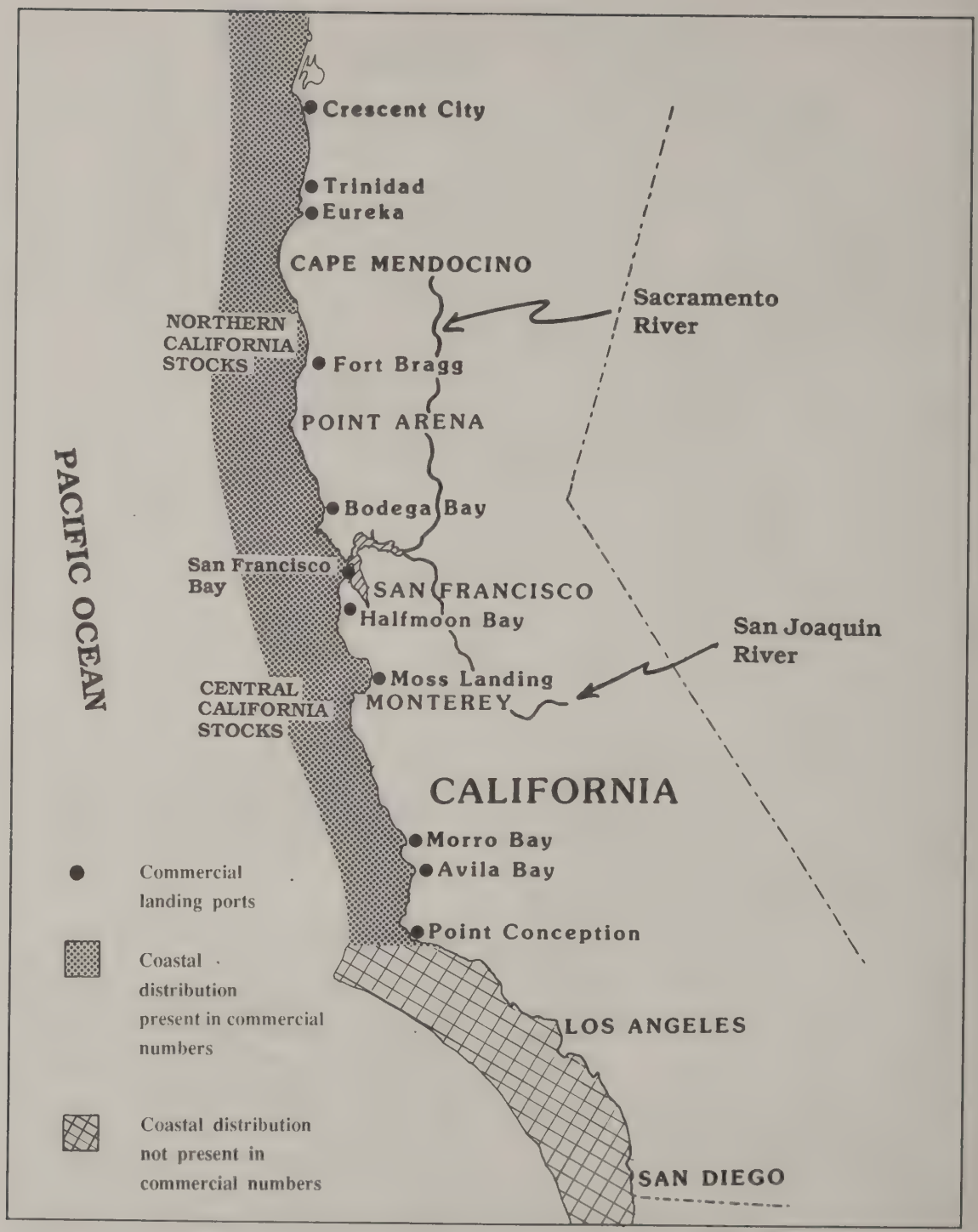

Figure 2. Distribution of the Dungeness crab in California.

highly sculptured; granular; widest at 10th tooth, no rostrum. Frontal area: narrow with five unequal teeth, not markedly produced beyond outer orbital angles; middle tooth largest, more advanced than outer pair; outer pair form inner angles of orbit. Teeth: (antero-lateral) 10, counting orbital tooth; widest at 10th tooth, which is large and projecting; all teeth pointed, with anterior separations. Posterolateral margins: unbroken, entire, without teeth, meet antero-lateral margins with distinct angle. Abdomen: narrow in male, broad in female (Figure 3). Chelipeds: fingers not dark; dactyl spinous on upper surface; fixed finger much deflexed; hand with six carineae on upper outer surface; wrist (carpus) with strong inner spine. Walking legs: rough above; broad and flat (especially propodus and dactylus of last pair). Juveniles: antero-lateral and postero-lateral margins meet at a distinct angle; carapace widest at 10th tooth; postero-lateral margin entire; carpus of cheliped with single spine above, fingers light colored; carapace not as broad as adults.

The red rock crab, *Cancer productus*, also has 10 antero-lateral teeth; frontal teeth are unequal. However, this species differs from *C. magister* in that the frontal area is markedly pronounced beyond outer orbital angles, cheliped fingers are black, and the carapace is widest at eighth antero-lateral tooth. It attains a width of 7 inches.

The rock crab, *Cancer antennarius*, like *C. productus*, is dark red with black-tipped chelae, is widest at the eighth tooth, but is red-spotted on its ventral surface. It attains a width of about 13 cm. *Cancer oregonensis* (Oregon *Cancer* crab) is a small, oval crab with 12 antero-lateral teeth. Both the slender crab (*Cancer gracilis*) and *Cancer jordani*, two rather uncommon species, have nine antero-lateral teeth; *C. gracilis* rarely exceeds a width of 8 cm. The yellow crab, *Cancer anthonyi*, which is found south of Humboldt Bay, has large smooth claws with black tips, is yellowish-brown with a wash of purple anteriorly, has 9 antero-lateral spines and attains a width of 15 cm. Identification keys to the genus *Cancer* were prepared by Kozloff (1974) and Carlton and Kuris (1975).

REASON FOR INCLUSION IN SERIES

The Dungeness crab supports a valuable commercial and sport fishery along the west

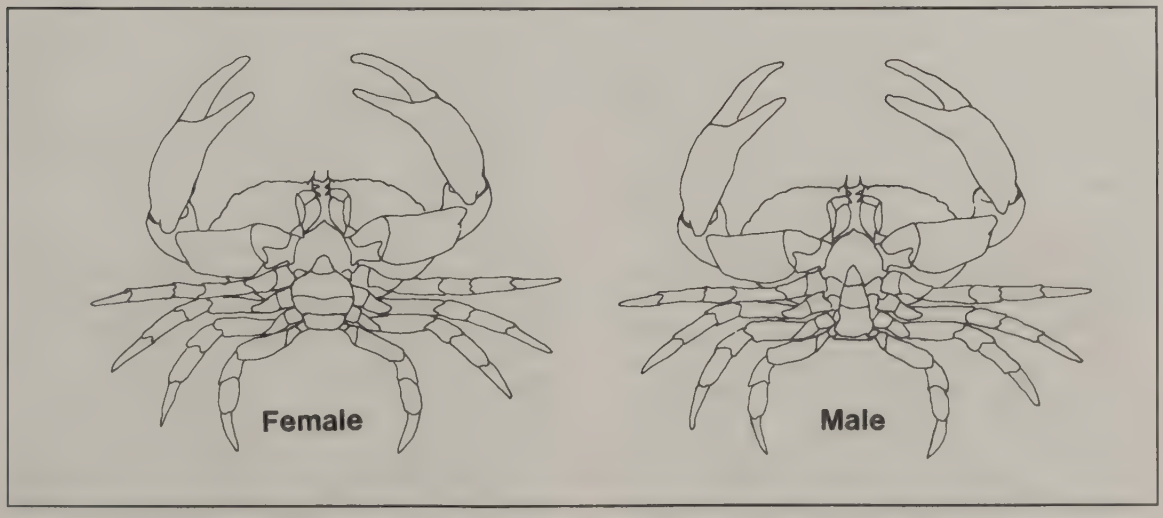

Figure 3. Abdominal differences between female (left) and male (right) Dungeness crabs. Only males, which possess a slender abdomen, may be kept by sport and commercial crabbers.

coast of the United States. It occupies ecological niches in both marine and estuarine waters and is ecologically important as both predator and prey at all life stages. Recent studies on the environmental consequences of dredging in estuaries have established a strong probability that the Dungeness crab population will be seriously reduced by habitat alteration from dredging unless proper precautions are taken to reduce losses (Armstrong et al. 1982; Stevens and Armstrong 1984). The loss of vital estuarine habitat could significantly reduce recruitment to the offshore fishery (Armstrong and Gunderson 1985).

LIFE HISTORY

Mating

Dungeness crabs mate from April to September in British Columbia (MacKay 1942; Butler 1956), mostly in March and April (D.A. Armstrong, unpubl. data) but sometimes in May and June in Washington (Cleaver 1949); and March to July in California (Poole and Gotshall 1965). Mating occurs in nearshore coastal locations in the west coastal region of the Pacific Northwest. Premolt female crabs are located by adult males for mating, possibly through a pheromonal homing system similar to those used by other crab species (Knudsen 1964; Edwards 1966; Hartnoll 1969). The female is held by the male in a premating embrace up to 7 days prior to her molting (Snow and Neilsen 1966). Approximately 1 h after molting of the female is completed, the hardshell male and softshell female mate. The male gonopods are inserted into the spermathecae of the female and spermatophores are deposited. Following copulation, the female may be embraced again by the male for a period of up to 2 days. Both premating and postmating embraces may serve to protect the female from predation, while insuring the mating success of the male by guarding the female against other males (Snow and Neilsen 1966). The male spermatophores in the spermathecae contain sperm that may be viable for many months (MacKay 1942), often through molting until a second egg extrusion (Orcutt 1978).

Eggs and Fecundity

Actively molting female crabs are more fecund than non-molting crabs, even though they may be the same size (Hankin et al. 1985). Eggs are not fertilized until extrusion, at which time they are attached to the female pleopod setae and are carried beneath the abdominal flap (MacKay 1942; Stevens 1982; Wild 1983); they hatch in 60 to 120 days. Eggs are extruded from September to February in British Columbia (MacKay 1942; Butler 1956), from October to December in Washington (Cleaver 1949; Mayer 1973), from October to March in Oregon (Waldrom 1958), and from September to November in California (Orcutt et al. 1976; Wild 1983). An egg mass may contain from one to two million eggs (Wild 1983), and a female may produce up to five million eggs in three or four broods during her lifetime (MacKay 1942). Eggs are orange at extrusion, becoming progressively darker in color as they develop (MacKay 1942; Cleaver 1949). Water temperatures and changes in water temperatures have considerable influence on the rate of egg development and mortality after fertilization and spawning. When temperatures rise, the rate of egg development also rises, but so does the rate of mortality. In laboratory tests (Wild 1983) eggs held at 9.4 °C hatched in 123 days and at 16.7 °C they hatched in 64 days. At 10 °C, 685,000 larvae were produced per egg mass, whereas at 16.7 °C, 14,000 larvae were produced per egg mass. Egg mortality for eggs from Similk Bay, Washington, was 20% after 20 min exposure at 10 °C; 30% after 4 min and 90% after 20 min at 15 °C; and 100% after 4 min at 20 °C (Mayer 1973).

Epibiotic fouling of Dungeness crab eggs has been linked to increased egg mortality because of mechanical interference with hatching and oxygen consumption (Fisher 1976; Fisher and Wickham 1976, 1977). Waters with high and rising nutrient levels are suspected to cause increased fouling. Egg predation by a nemertean worm, *Carcinonemertes errans*, is thought to increase the fouling of eggs through the liberation of yolk during its feeding and defecation (Wickham 1979a, 1979b). In coastal waters near San Francisco, the estimated average annual mortality caused by predation of

the worm on Dungeness crab eggs was over 55% in 1974-79 when worm densities were about 14 per 1,000 eggs (Wickham 1979b).

Eggs hatch in 2 to 3 months (Cleaver 1949; Orcutt 1978; Wild 1983). The hatching season commonly shortens from north to south along the Pacific coast. Eggs hatch in coastal waters from December to June in British Columbia, but considerably later in Queen Charlotte Islands (MacKay 1942; Butler 1956), from January to April in Washington (Cleaver 1949; Armstrong et al. 1981), from December to April in Oregon (Reed 1969; Lough 1976), from January to early March in northern California (Wild 1983), and commonly from late December to early February in central California (Wild 1983).

Larvae

Larvae emerge as prezoeae and molt to zoeae within about 1 h, but the prezoeal period varies with salinity (Buchanan and Milleman 1969). The larvae progress through five zoeal stages before molting into megalops (Figure 4; Poole 1966; Reed 1969; Lough 1976). In central California, first stage zoeae appear between mid-December and early January, and fifth stage zoeae appear between mid-February and mid-March; about 80-95 days are required to complete the five zoeal stages in California (Reilly 1985). Zoeae first appear 5-16 km from shore (Lough 1976; Orcutt 1977; Reilly 1983a). In both central and northern California, zoeae are almost always found in the ocean, not the bays (Reilly 1985). Of hundreds of estuarine samples, only two contained zoeae; of several thousand oceanic samples, about 2,000 contained zoeae (Reilly 1985). Dungeness crab larvae appear to be unique among larval brachyurans in central California in this respect and are the most abundant first stage zoeae present at offshore depths greater than 30 m (Reilly 1985). All four of the other *Cancer* crabs of central California--the red crab (*C. productus*), the slender crab (*C. gracilis*), the rock crab (*C. antennarius*), and the yellow crab (*C. anthonyi*)--occur as first stage zoeae in San Francisco Bay (Reilly 1985). Offshore movement and distribution of Dungeness crab larvae are probably regulated by a variety of factors, including depth, latitude, temperature, salinity, and ocean currents (Reilly 1983a, 1985). Multiple regression analysis indicated that depth is the most important independent variable that is correlated with larval distribution offshore (Reilly 1983a, 1985). Distribution is also dependent upon the larval stage, and the larvae show a diel pattern of vertical distribution; they are near the surface at night and at depth during the day (Reilly 1983a, 1985). Considerable offshore movement of larvae occurs during the zoeal stages; the larvae appear to be transported seaward from the onset of hatching (Reilly 1983a). Hatfield (1983) indicated that Dungeness crab zoeae appear to move offshore and presumably alongshore during late winter and the winter-to-spring transition period. After upwelling occurs around April and May, the megalops (advanced stage) appear in large nearshore concentrations, although the mechanism by which they move inshore is unclear.

The megalops (advanced) stage of the Dungeness crab is found from May to September off the coast of British Columbia. It is the last pelagic stage. In Washington coastal waters, the megalopae first appear in April; abundance peaks in May through June. In Oregon waters, they are most abundant in April and May (MacKay 1942; Cleaver 1949; Butler 1956; Lough 1976; Stevens 1982). Dungeness crabs spend 25-30 days as megalopae in California where they first appear in early March, but may appear as late as mid-April (Reilly 1985). This trend of abundance indicates larval development ends later proceeding from south to north. Off Oregon, megalops are carried within 1 km of shore by tidal currents and by self-propulsion (Lough 1976). Megalopae often are abundant on the hydrozoan *Velella velella*, when they are scarce or absent elsewhere in the water column (Wickham 1979c; Stevens and Armstrong 1985). Wickham (1979c) suggested that *V. velella* aids in the movement and distribution of megalops and possibly provides a food source and protection from predation.

Larvae eat both zooplankton and phytoplankton, but zooplankton is most important (Lough 1976). The larvae capture food items with the natatory hairs of their

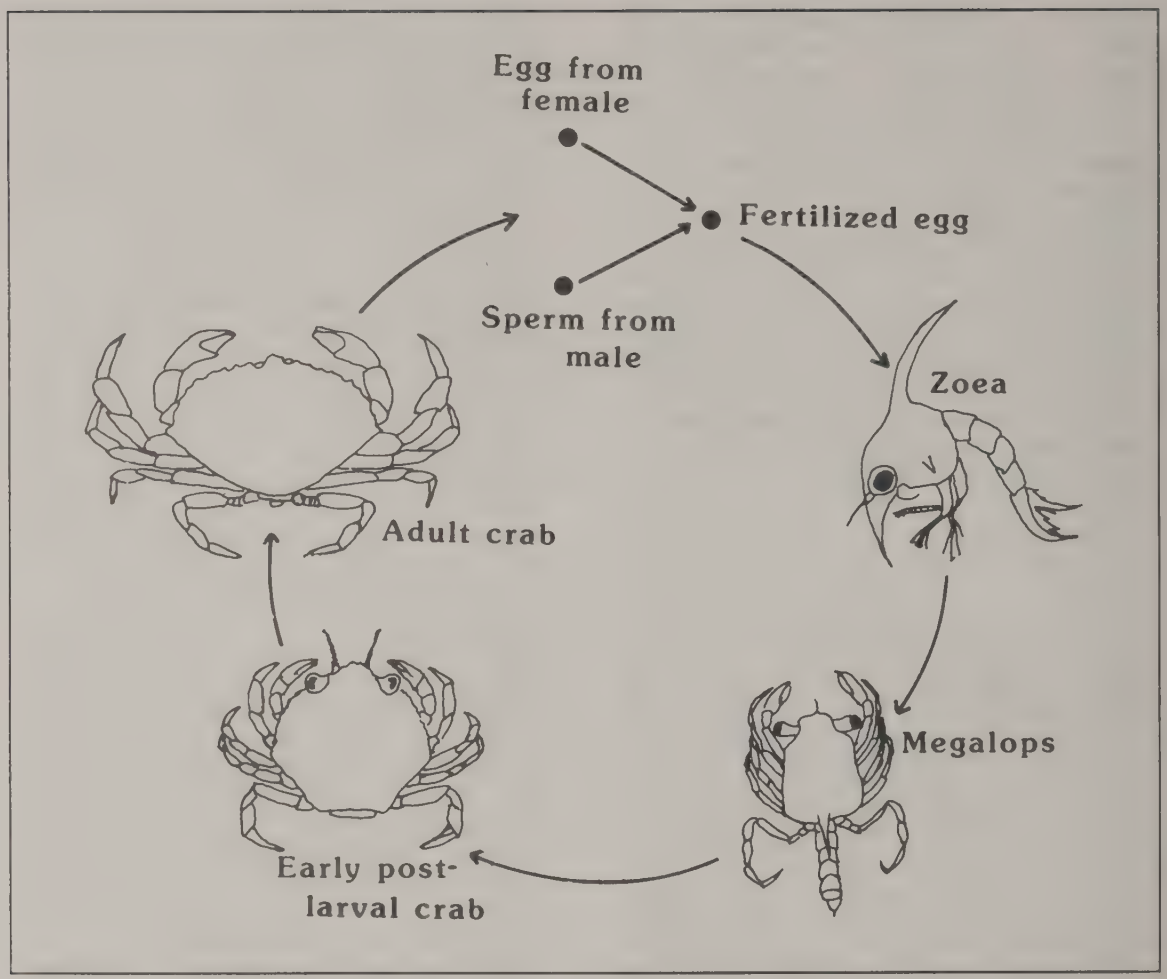

Figure 4. Life cycle stages of the Dungeness crab: Zoea, megolops, postlarva (juvenile), and adult.

maxillipeds, and size of food is a selection factor (Lough 1976; Armstrong et al. 198l).

Information on larval predators and predation rates is scarce. Zoeae are thought to be consumed by numerous types of planktivores (Stevens 1982); megalopae are preyed upon by many fishes, including coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*), according to Orcutt et al. (1976) and Reilly (1983b). Heavy predation by salmon may have caused the decline of the Dungeness crab catch in the San Francisco Bay area (Reilly 1983b). There appears to be a direct relationship between coho salmon hatchery production in Oregon and the magnitude of predation on the megalopae in California waters (Reilly 1983b). In a study of food habits, the combined stomachs of eight coho salmon contained 1,061 megalops (Orcutt 1977); in a separate study (MacKay 1942) up to 1,500 megalopae were found in the stomach of a single fish. Prince and Gotshall (1976) found Dungeness crab megalops and instars, the stages between postlarval (including adult) molts, to be the most important food of copper rockfish

(*Sebastes caurinus*) in northern California's Humboldt Bay.

The abundance of a year class depends in part on larval survival to metamorphosis (Peterson 1973; Wickham et al. 1976; McKelvey et al. 1980). Natural larval mortality is probably high because of a combination of predation, excessively high or low water temperatures and fluctuations, a scarcity or low quality of food, and currents affecting distribution (Lough 1976; Armstrong 1983).

Juveniles

Most megalopae molt into juveniles in August off the coast of British Columbia (Figure 4; MacKay 1942; Butler 1956), and in April-May off the coasts of both Oregon (Lough 1976) and Washington (Stevens 1982). After molting, the juveniles are found in shallow coastal waters and estuaries, and large numbers live in beds of eelgrass (*Zostera* sp.) or other aquatic vegetation that provide protection and substrate and harbor food organisms for early instars (Butler 1956; Orcutt et al. 1975; Stevens and Armstrong 1984, 1985). Recently, shells of bivalves such as the softshell clam (*Mya arenaria*) and the Pacific oyster (*Crassostrea gigas*) have been documented as very important habitat for young Dungeness crabs (Armstrong and Gunderson 1985). In central California, there is evidence that movement of postlarval Dungeness crabs into the estuaries takes place in May and June via bottom currents, where they stay for 11-15 months (Tasto 1983). Juveniles are more common in estuaries, while subadults and adults are more common offshore. The importance of estuaries to juvenile Dungeness crabs has been discussed in detail (Tasto 1983; Armstrong and Gunderson 1985; Stevens and Armstrong 1985; Emmett and Durkin 1985). Dungeness crab tag recovery data in California show a regular pattern of movement of juvenile crabs out of estuaries and a random movement of adult crabs in the ocean (Collier 1983). Armstrong (1985) noted that spawning takes place offshore, which would be a major reason for adults moving out of the estuaries.

Juveniles molt 11 or 12 times before sexual maturity (Butler 1960, 1961b). Carapace width at the first instar (the first benthic stage) varies from about 5 mm to greater than 8.5 mm (Cleaver 1949; Waldrom 1958; Butler 1960, 1961b; Poole 1967). After 1 year of growth beyond hatching, most crabs in Bodega Bay, California, are in their 8th, 9th, or 10th instar (Poole 1967). By comparison, crabs from Grays Harbor, Washington, only attain the sixth or seventh instar by the end of their first year of life (Stevens and Armstrong 1984). Carapace width (CW) after the first year averages 44 mm in Grays Harbor, while the range is 63-94 mm in Bodega Bay (Poole 1967; Stevens et al. 1982). The crabs mature after about 2 years (Butler 1961b) at about 116 mm CW for males and 100 mm for females (Butler 1960).

The diet of juvenile crabs consists largely of fish, mollusks, and crustaceans (Butler 1954; Gotshall 1977; Stevens 1982). Juvenile Dungeness crabs, 10-30 mm CW, forage for the small, estuarine bivalve, *Transennella tantilla* (Asson-Bates 1986). In Grays Harbor, Washington, first-year juveniles <60 mm CW feed primarily on small mollusks and crustaceans. Second-year crabs, 61-100 mm CW, feed on fish and prefer *Crangon* shrimp (Stevens et al. 1982). Fish also are important to northern California crabs < 100 mm CW according to Gotshall (1977), but Butler (1954) reported that crustaceans were the primary food among crabs of this size in the Queen Charlotte Islands, British Columbia. Cannibalism among Dungeness crabs has been noted by various authors (MacKay 1942; Butler 1954; Tegelberg 1972; Gotshall 1977; Stevens 1982; Stevens et al. 1982). Cannibalism was most prevalent among crabs < 60 mm CW which fed on smaller crabs of the same year class, probably during molting (Stevens 1982; Stevens et al. 1982). Cannibalism is cited as a possible cause of the dramatic population cycles characteristic of the Dungeness crab fishery (Botsford and Wickham 1978).

Juveniles are eaten by a variety of demersal fishes in the nearshore area, among which the most important are various flatfishes--starry flounder, *Platichthys stellatus*; English sole, *Parophrys vetulus*; and rock sole, *Lepidopsetta bilineata* (Reilly 1983b). Other predators on

juvenile crabs are lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), wolf-eels (*Anarrhichthys ocellatus*), rockfish (*Sebastes* spp.), and octopus (*Octopus dofleini*), according to Waldrom (1958) and Orcutt (1977). Predation on Dungeness crabs may be seasonal in nature, as observed in white sturgeons, *Acipenser transmontanus* (McKechnie and Fenner 1971). Predation on Dungeness crabs may have a devastating impact as in the case of sea otters (*Enhydra lutris*) in Orca Inlet, Alaska (Kimker 1985b).

Adults

At about 4 years old, most adult Dungeness males in the coastal waters of Washington are of marketable size (>159 mm) (Cleaver 1949; Williams 1979). Marketable crabs usually molt only once a year (MacKay 1942). The maximum life span of Dungeness crabs is 8 to 10 years. The maximum size attained is about 218 mm CW in males and 160 mm CW in females at the 16th instar (MacKay 1942; Butler 1961b).

Adult Dungeness crabs occur primarily in the ocean but are also abundant in inland coastal waters. Along the coast of northern California, legal-sized and large sublegal-sized male crabs probably move offshore (often to the south or north) in late summer, sometimes through early winter; during winter the direction of movement is probably reversed and the crabs return inshore. Interannual variation in the predominant direction of movement is considerable (Gotshall 1978b). Collier (1983) has shown a random movement of adult crabs in the ocean. Many adult female crabs tagged off the coast of northern California moved relatively little (about 2 km) after 1 year (Gotshall 1978b; Diamond and Hankin 1985). These tagging studies indicate that adult female crabs constitute extremely localized stocks in northern California. However, Soule and Tasto (1983) reported that Dungeness crabs found in different areas along the Pacific Coast exhibited low levels of electrophoretic variation, indicating that this species dispersed widely and prevented local gene differentiation of populations.

Clams are the most important food of adult Dungeness crabs ≥ 151 mm CW in northern California (Gotshall 1977) and ≥ 166 mm CW in British Columbia (Butler 1954). Crustaceans and fish are valuable foods of the adult Dungeness crabs from both Similk Bay and Grays Harbor, Washington (Mayer 1973; Stevens et al. 1982). Dungeness crab populations are apparently not limited by the abundance or scarcity of particular foods because they are nonspecific feeders that readily adjust to various foods (Gotshall 1977). They have developed a feeding preference for biota on mud-sand substrate (Lawton and Elner 1985).

Crabs of different ages or sizes tend to eat different sizes or kinds of food (Stevens 1982; Stevens et al. 1982). According to Stevens et al. (1982), crabs progress from eating bivalves their first year after settlement, to eating shrimp (*Crangon* spp.) their second year, and finally to eating juvenile teleost fish in the third year; these shifts may be caused purely by changes in mechanisms of food handling, or they may have evolved to reduce competition among age groups of crabs. Crabs display a definite diel activity; they are more abundant by day in the subtidal area and more abundant at night in the intertidal area; the response is positively correlated with food availability (Stevens et al. 1984). Cannibalism is common among adults, but no correlations have been made between the rate of cannibalism and abundance (Stevens 1982; Stevens et al. 1982).

GROWTH CHARACTERISTICS

In Dungeness crabs, like other crustaceans, growth proceeds in steps through a series of molts. The general process of crustacean growth has been described by Barnes (1974) and Warner (1977). The number of molts that a crab undergoes before becoming mature depends upon the growth increment at each molt and the frequency of molting, both of which vary among crabs at different locations. Dungeness crabs grow in carapace size at each molt and gain biomass between molts. In older crabs the growth, as measured by the percent change in carapace width, declines as the frequency of molting slows down, but the rate of weight gain increases over time. The probability of annual molting in female Dungeness

crabs declines from about 1.0 for crabs of 130-135 mm CW to 0.0 for crabs of 155 mm CW and larger (Hankin et al. 1985).

Among possible attributes of estuarine residence suggested by Stevens and Armstrong (1984) is an enhanced growth rate compared to that of siblings of a year class that settle offshore. Size attained by juvenile crabs within certain periods after metamorphosis seems to be somewhat dependent on latitude and on time of settlement. Upper estimates of age at sexual maturity range from 4-5 years in British Columbia (MacKay and Weymouth 1935) to 1 year in San Francisco Bay, where the crabs reach by this time a carapace width (100 mm) usually associated with sexual maturity (Tasto 1983). More generally, crabs are predicted to reach maturity at the end of their second year after metamorphosis or in their third growing season over much of the coast (Butler 1961b; Cleaver 1949). While age and size at sexual maturity may not differ substantially along the coast, estimates of growth rates of newly settled age 0+ crabs do.

Several studies of juveniles indicate that growth rate is accelerated in estuaries or within nearshore coastal embayments where water temperatures are relatively high (Stevens and Armstrong 1984; Armstrong and Gunderson 1985). This difference in growth rate may be due to a temperature difference which is approximately 6 °C higher in the estuary than the ocean (Armstrong and Gunderson 1985).

Growth of young-of-the-year crabs is substantially slower offshore from San Francisco Bay, in the Gulf of the Farallons, than in estuaries (Tasto 1983), where the offshore crabs are about 28-30 mm and those in the estuary are about 60 mm in width. Gulf-reared crabs require about 2 years after metamorphosis to reach the first postlarval instar width of 100 mm, while the average bay-reared crab reaches this size one year after metamorphosis (Tasto 1983).

Growth of California Dungeness crabs is somewhat faster in males than females (Figure 5), but varies from year to year and among geographic regions (Tasto 1983). In northern

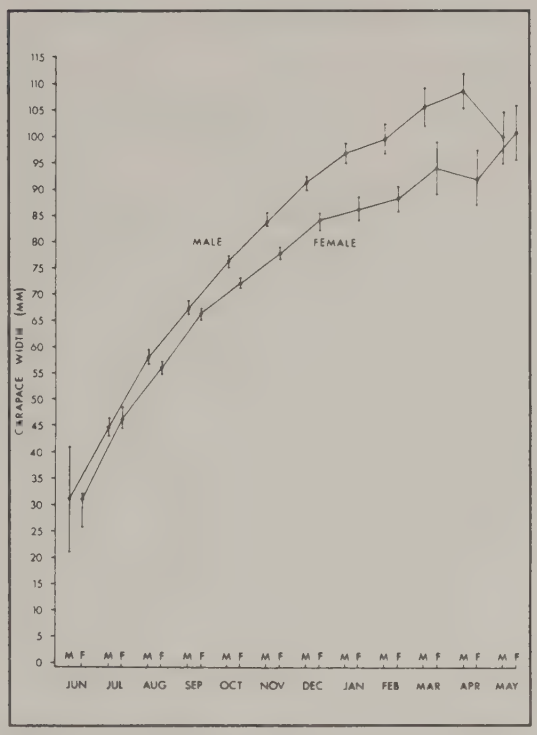

Figure 5. Mean carapace width of male and female crabs from central California, 1977-80.

California, age and growth are similar to that observed in Washington, where crabs become fully recruited into the fishery at 4 years of age, having reached a carapace width of about 159 mm (Warner 1985b; 1987). Dungeness crab growth is variable along the Pacific coast. However, in general, it is somewhat slower in the northern part of the range (Washington and British Columbia) when compared to the southern part of the range (California).

THE FISHERY

Commercial Fishery

Commercial landings of Dungeness crab on the Pacific coast have fluctuated widely, almost cyclically, over the past 30 years (Figure 6) and have been reviewed by Armstrong (1983). The cyclical characteristics of the catches were most

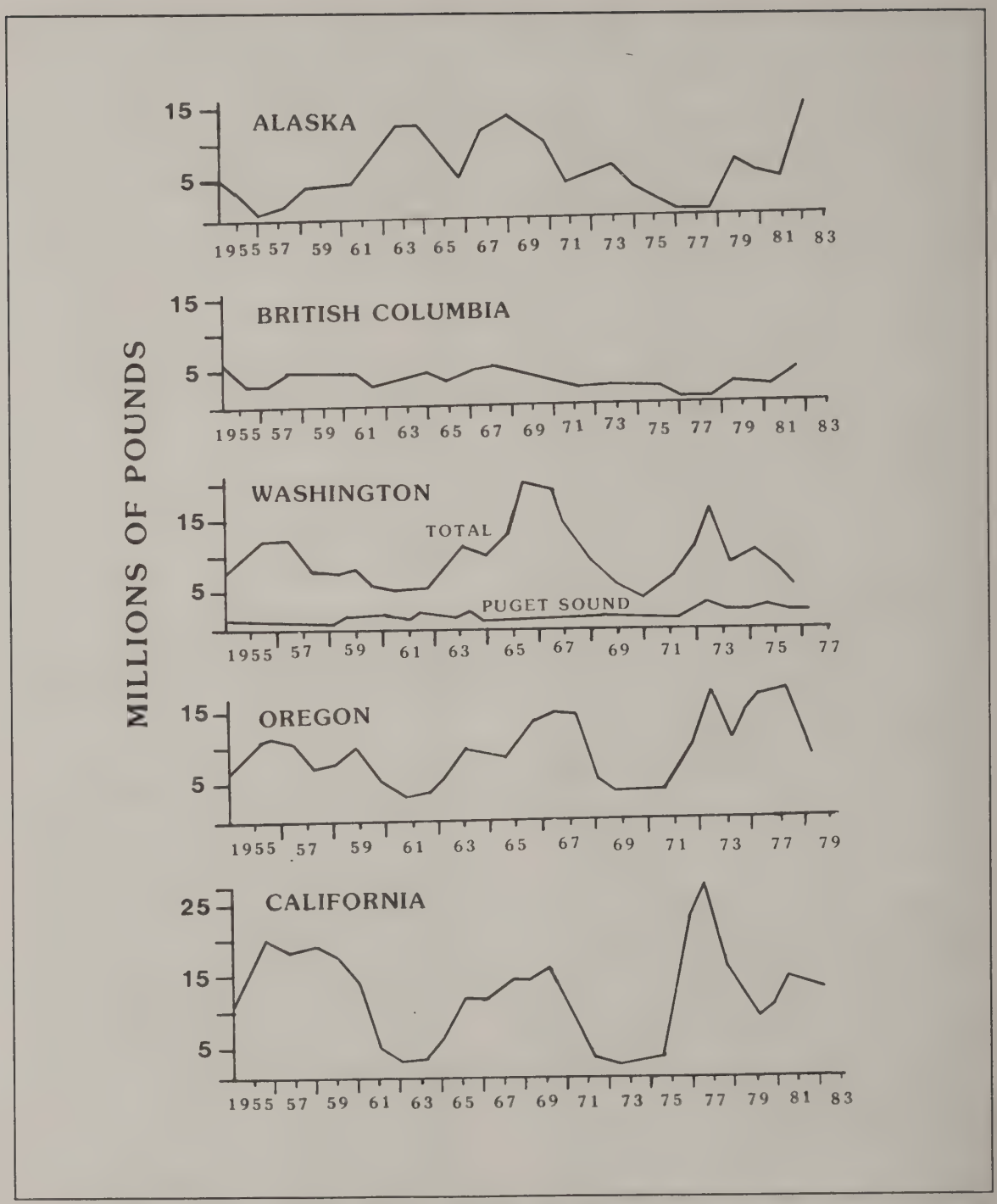

Figure 6. Dungeness crab landings by season in Pacific Coast States and in the Province of British Columbia, 1955-83.

noticeable in northern California (Gotshall 1978a; Farley 1983; Dahlstrom and Wild 1983; Warner 1985a). Several hypotheses have been proposed to explain the cyclic nature of Dungeness crab population size. According to Peterson (1973), commercial landings were highest 1.5 years after a period of strong upwelling in California and Oregon, and 6 months following a strong upwelling in Washington, although the biological sense of such a relation is much in doubt. Botsford and Wickham (1975) challenged this conclusion by using autocorrelation to show that commercial landings are cyclic but that strong upwelling is not.

Another hypothesis to explain catch fluctuations suggests that periods of high levels of cannibalism and interspecific competition may cause a decline in the fishery 3 or 4 years later (Botsford and Wickham 1978). In a model predicting recruitment, McKelvey et al. (1980) discounted cannibalism as a factor and contended that changes in egg and larval survival regulate population success. Larval survival may be seriously reduced by a combination of environmental factors that can cause increased mortality if unfavorable for even short periods of time (Lough 1976). Stevens and Armstrong (1981) indicate that diseases caused by various organisms (bacteria, Protozoa, or fungi) may be responsible for mass mortalities of adult crabs. Predation may have a profound impact on the Dungeness crab commercial fishery in certain geographic areas (Kimker 1985b). Reilly (1983b) hypothesized that extensive predation by hatchery-released coho salmon from the Columbia River continually suppressed the Dungeness crab fishery. There is an apparent cyclic covariance between abundances of salmon and Dungeness crabs (Botsford et al. 1982).

Dungeness crab landings from 1954 to 1983, divided by State and Province (Figure 6), show that landings in Washington (except Puget Sound), Oregon, and California generally followed similar trends. Landings from Puget Sound and British Columbia are lower and show less annual variation. Alaska landings bear little relation to other areas of the Pacific Northwest. Recent reviews of the commercial Dungeness crab fishery have been published for Alaska (Eaton 1985; Kimker 1985b; Koeneman 1985; Merritt 1985), British Columbia (Jamieson 1985), Washington (Barry 1985), Oregon (Demory 1985), and California (Dahlstrom and Wild 1983; Warner 1985a).

California has five commercial Dungeness crab fishing areas: (1) Eureka to Crescent City; (2) Fort Bragg; (3) San Francisco to Bodega Bay; (4) Monterey; and (5) Avila Bay to Morro Bay (Figure 2). The commercial fishery extends south to Point Conception. Two major populations of Dungeness crabs are commercially exploited in California (Warner 1985a)--those from northern California and those from central California (Figures 2 and 7). Point Arena is the division between these two fisheries, according to Farley (1983). Central California catches have been low since about 1962 (Figure 7), whereas in northern California good catches for about 6 years have alternated with poor catches of about 4 years (Figure 7). Crescent City has been the major port of landing in California (Warner 1985a).

Only male crabs 6-1/4 inches wide or wider may be taken commercially in California. Not more than 1% of any catch may be smaller than this size and no crabs less than 5-3/4 inches may be retained (Warner 1985a). Most crabs taken in the California commercial fishery are 4-year-olds, although some 3- and 5-year-old crabs are taken (Warner 1985a).

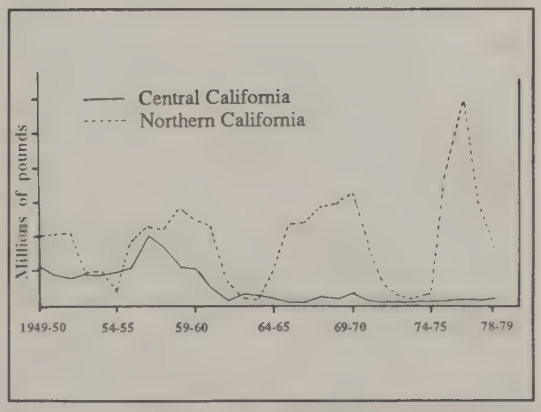

Figure 7. Dungeness crab landings for central and northern California (Farley 1983).

Sport Fishery

Sport catch data are scarce and according to Barry (1985) the Washington sport fishery on Dungeness crabs amounts to less than one percent of the annual commercial harvest. Most of the available sport catch data are from a survey reported by Williams (1979). He revealed that from April through August 1974, 471 crabs were taken intertidally at Mission Beach, Washington, by 735 sport crabbers. April, May, and June produced the best sport catches, with the highest average catches occurring on low tides that ranged from -0.60 to -0.74 m. Aerial surveys made over Puget Sound beaches using Williams' (1979) survey data estimated that the beaches of Washington State probably supported about 20,000 crabbers during those months in 1974. In 1975 in Washington, the sport crab pot fishery alone accounted for the harvest of about 300,000 Dungeness crabs (Tegelberg 1976). Other sport catch methods are ring nets, dip nets, and hook and line.

Although both male and female crabs may be taken in the California sport fishery (Figure 3), there is a minimum size for both sexes of 6-1/4 inches, measured in front of the 10th anteriolateral spines. The daily catch limit is 10 crabs. Concern over the excessive take of sublegal sized Dungeness crabs in the sport fishery prompted the California Fish and Game Commission in 1978 to close the fishery in San Francisco and San Pablo Bays inside Golden Gate (Dalstrom and Wild 1983). Sport fishing for Dungeness crabs is most active in the Crescent City area (Dalstrom and Wild 1983). Nearly 4 times more red crabs (*C. productus*) than Dungeness crabs are taken in the sport fishery. Rock crabs, slender crabs, and yellow crabs are also taken in the sport fishery in limited numbers.

A useful publication for sport crabbers in California by Phillips (1973) describes the common members of the genus *Cancer* and the gear used to catch them.

ECOLOGICAL ROLE

Dungeness crabs consume a wide variety of food organisms and are prey to numerous predators. Crabs contribute to several trophic levels as they progress through successive life stages. The larvae largely consume plankton (Lough 1976) and are preyed upon by numerous fishes. Adults and juveniles are preyed upon by sea otters, fishes, and octopuses (Butler 1954; Waldrom 1958; Stevens 1982; Reilly 1983b; Kimker 1985b). Cannibalism is common and probably exercises some control over abundance. In their various life stages, Dungeness crabs feed on a variety of mollusks, crustaceans, and fish species (Stevens et al. 1982). Other information on the ecological role is given in the life history section.

ENVIRONMENTAL REQUIREMENTS

Temperature

The temperature preferences of adult crabs are different among seasons (Mayer 1973). They are somewhat tolerant of abrupt temperature and salinity fluctuations (Cleaver 1949) and water temperatures from 3 to 19 °C were listed as normal for the Dungeness crab (Cleaver 1949).

Dungeness crabs have different optimal water temperatures at different stages. In the laboratory, Des Voigne (1973) reported that optimal water temperatures for mating ranged from 12 to 16 °C during long photoperiods. Wild (1983) noted an apparent trend towards crabs mating later in colder water in his laboratory experiments, and noted that mating took place between 10 and 17 °C. Other factors that were not controlled may have interacted with temperature to produce Des Voigne's (1973) and Wild's (1983) results. In Washington coastal waters, where Dungeness crabs usually mate in early spring, when the bottom temperatures are between 8 and 10 °C (Armstrong, unpubl. data). Reported spawning temperatures vary partly because they are not based on well-managed experiments. According to Wild (1983), the egg brooding periods varied inversely with seawater temperatures of 9 to 17 °C (Figure 8). Moving northward along the Pacific coast, prolonged egg brooding periods in colder water are consistent with prolonged occurrences of ovigerous crabs and cooler ocean

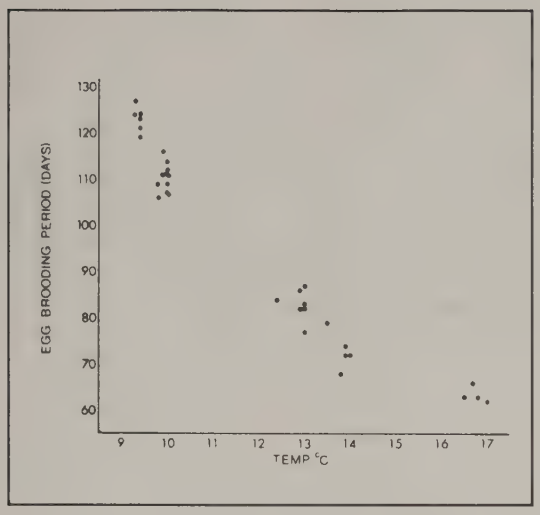

Figure 8. Egg-brooding periods of the Dungeness crab at various laboratory seawater temperatures.

temperatures (Wild 1983). Hatching success, considered as the number of larvae that hatch from an egg mass, decreased as the temperature increased from 10 to 17 °C (Wild 1983). Mayer (1973) found a similar correlation between egg mortality and temperature with 20% mortality after 20 min at 10 °C and 100% mortality after 4 min at 20 °C.

Optimal temperatures for larvae are 10 to 14 °C. Juvenile crabs, 80 mm wide and acclimated to 10.0 °C, have been exposed to water temperatures up to 25.0 °C for 7 days with little or no mortality (Des Voigne 1973); however, an increase to 27.5 °C was fatal to 100% of all crabs tested. In the laboratory, adult crabs had a maximum tolerable temperature of 25 °C during long photoperiods, which decreased to 20 °C when exposed to short photoperiods (Des Voigne 1973). With adult crabs held for 8 months, Wild (1983) observed that mortality increased with temperature from 17% at 10 °C to 58% at 13 °C and to 80% at 17 °C, although laboratory stress probably exacerbated the effect of high temperatures.

Salinity

Tolerance to salinity varies among the life stages of the Dungeness crab. In general, salinity is not as important as temperature to egg development and hatching, but the larvae are highly sensitive to changes in salinity (Buchanan and Milleman 1969). The percentage of eggs hatching was optimum at 15 ppt, but hatching occurred to some degree over a wide range of salinities between 10 ppt and 32 ppt (Buchanan and Milleman 1969). When salinity was increased from 15 ppt to 32 ppt, the average prezoeal period was reduced from about 60 min to less than 11 min. At a salinity of 10 ppt, no prezoeae molted to zoeae, but 100% molted at 30 ppt (Buchanan and Milleman 1969). The highest survival for larvae was between salinities of 25 ppt and 30 ppt (Reed 1969). Survival decreased with salinity and was poorest at salinities of 15 ppt; salinities lower than 15 ppt are also lethal (Reed 1969). Sugarman et al. (1983) demonstrated that adult Dungeness crabs close (by retracting their appendages and tightly closing their buccal cavity) and stop all overt activity to prevent ionic exchange at 36.2 ppt (upper limit) and at 15.5 ppt (lower limit).

Temperature-Salinity Interactions

Salinity and temperature are both related to larval survival. Significant interaction exists between these two factors, with salinity buffering the effects of temperature. At favorable temperatures, unfavorable salinities resulted in complete mortality of adults, but favorable salinities at unfavorable temperatures allowed some survival (Reed 1969). The most obvious effect on growth rate occurred at temperatures that resulted in the best survival. Salinities that favored survival generally had little effect on zoeal growth. Survival of zoeae is optimal between the water temperatures of 10.0 and 13.0 °C and salinities of 25 and 30 ppt (Reed 1969). The significant interaction between temperature and salinity dictates caution when making statements about either variable independent of the other one. The effects of temperature or salinity alone on *C. magister* zoeae do not appear to cause large

fluctuations in zoeal survival in the ocean (Reed 1969; Lough 1976).

Substrate

Adult crabs are found living over several substrate types (Schmitt 1921; Cleaver 1949; Butler 1956), but they prefer sandy-mud bottoms (Karpov 1983; Lawton and Elner 1985). Early juveniles prefer beds of eelgrass, shell, or sandy mud (Stevens and Armstrong 1984). This preference may stem from an abundance of food organisms on such substrates or perhaps the crabs find shelter from predation there (Stevens 1982). Older crabs seem less dependent on epibenthic cover and can be found over more exposed substrates. Most crabs remain in the subtidal environment, but may venture into littoral areas at high tide (Stevens et al. 1984). The presence of preferred food items enhances this behavior, while low salinities following heavy rains decrease it.

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the taxonomy, life history, and environmental requirements of coastal aquatic species. They are designed to assist in environmental impact assessments. The Dungeness crab (*Cancer magister*) is found in California estuaries and off the coast of California. It is a shellfish highly prized and sought after by both commercial and sport fishermen. Commercial landings in California have fluctuated widely, almost cyclically, over the past 30 years. In the California sport fishery, a minimum size of 6.25 inches carapace width has been established. Dungeness crab have a life cycle that involves several metamorphic stages: zoea, megalops, postlarval crab, and adult crab. Normal temperatures for Dungeness crabs are 3 to 19 °C. Optimum salinity for egg hatching is about 15 ppt, but the survival rate of larvae is highest at salinities of 25 to 30 ppt.

17. Document Analysis a. Descriptors

Estuaries
Fisheries
Crabs
Salinity
Temperature
Feeding habits
Life cycles
Growth
Sediments
Depth

b. Identifiers/Open-Ended Terms

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Cancer magister
Life history
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